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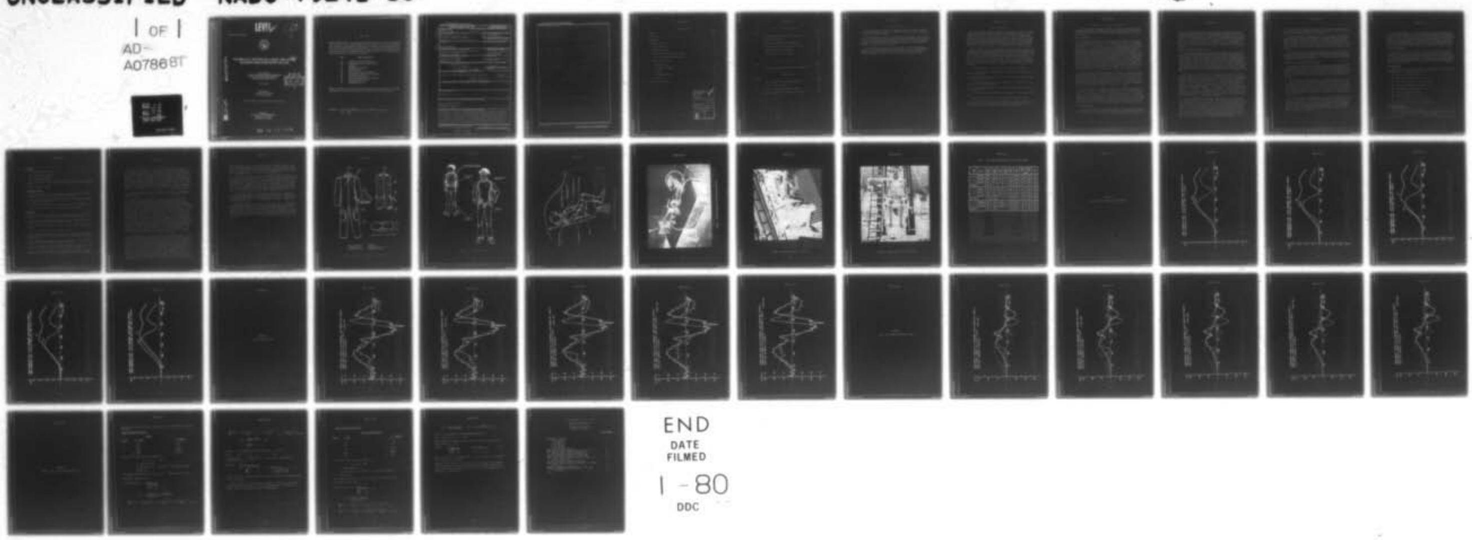

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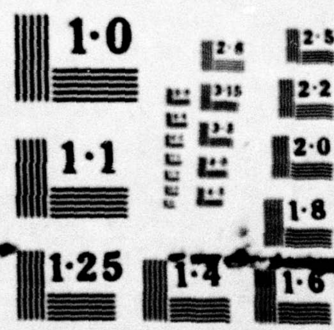

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MICROCOPY RESOLUTION TEST CHART

REPORT NO. NADC-79241-60

FEASIBILITY TESTING OF A BODY INFLAT~~ION~~able BLADDER (BIB) RESTRAINT DEVICE

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April 10, 1979

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A feasibility model of an inflatable type restraint system was designed and developed for use with existing operational restraint hardware to improve crewman safety during ejection. The vest type inflatable system is worn over the flight suit and under the MA-2 integrated torso harness. Upon inflation, the crewman is forced back into the suit while slack is removed from the harness. Subsequent ejection tower testing has demonstrated significant reductions in horizontal head and torso response during the catapult phase of the ejection.

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I N T R O D U C T I O N

This interim report covers a 6.2 research effort to determine the feasibility of an inflatable bladder type restraint system for use by crewmembers ejecting from military aircraft.

This program was sponsored by the Naval Air System Command, Code Air-304 B under the continuing Exploratory Development Phase studies, with the objective to develop and evaluate the feasibility and practicality of various proposed approaches to achieving specific operational functions, to satisfy new requirements or improve current deficiences.

This effort was conducted under the sub-task title, "In-flight Escape Systems, Positioning and Restraint," which is involved in the development and testing of ejection seat subsystems and components to assure optimum body position and restraint during in-flight escape and parachute recovery.

BACKGROUND

Past and current reviews of ejection seat statistics continue to clearly indicate that current restraint systems do not adequately protect the crewmember during the entire mission profile, and certainly not during adverse flight conditions such as buffeting and turbulence, high 'G' maneuvering, uncontrolled flight, and during emergency ejection. Aside from the high speed ejection injuries, the data further shows that injuries are being sustained during the cockpit egress phase of the ejection as well as during parachute opening loads. In many cases, multiple injuries are being sustained. The need to provide means to position and restrain the man is well documented.

Naval aviators flying in high performance aircraft normally wear the MA-2 integrated torso suit which serves both as a parachute jump harness and as a restraint system during flight and ejection. A recent survey showed that less than 50 percent of pilots questioned fly with a tight restraint system. Most pilots adjusted their harness attachments "snugged" and some purposely fly loose. There are thirteen different sizes of the MA-2 harness and approximately one-third of all pilots questioned stated that they were not specially fitted for the harness that they were using. The combination of an improperly fitted MA-2 harness and a loosely adjusted restraint contributes to the following:

1. Cause the pilot to submarine under the lap belt resulting in:

a. Poor body position during application of the ejection loads, causing possible spinal injury

b. Contact of aircraft structure with the arms and/or legs during egress of the seat from the cockpit.

2. Cause additional loads on the crewmember due to amplification of the ejection forces (dynamic response).

3. Negate the effectiveness of the inertia reel action after or during positioning (haulback).

4. Contributes to seat instability and flailing of the crewman's extremities.

5. Cause additional loads on the crewman during parachute opening.

A number of investigations and developments are currently on-going, utilizing various methods and techniques for reducing injuries sustained during cockpit egress because of misadjusted or ineffective equipment.

TECHNICAL DISCUSSION

The system under investigation is one of a number of concepts being investigated as a means of assuring optimum body positioning and restraint to reduce injuries related to the cockpit egress/acceleration phase of the ejection sequence.

SYSTEM DESCRIPTION

The concept being developed uses an inflatable system which can be designed and integrated directly into the flight suit coveralls, (see figure 1) or separately as a vest (figure 2). Upon initiating ejection, and following canopy removal, the seat inertia reel will fire simultaneously with the source of inflation. As the inertial reel pulls or tightens the upper torso back against the seat, as may be necessary, the body inflatable bladder (BIB) system inflates. The bladders are located between the man and the seat attached restraint/parachute harness. The MA-2 integrated torso harness, which is worn over the flight suit and/or the proposed BIB vest, is the restraining equipment against which the inflated bladders force the occupant against the seat. The inflated bladders push the crewman's upper torso tightly against the back of the seat while also inflating underneath the lap belt pushing the hips down snugly into the seat pan. This action forces the crewmember to assume a proper and secure pre-ejection position (figure 3) by removing all the slack from the restraint system, and it negates the effects of any crewman either purposely or inadvertantly flying with a loose restraint. The entire inflation sequence is accomplished in less than 100 miliseconds.

During the seat/man separation sequence, the seat restraint and inflation hose are disconnected in the normal manner. Incorporation of a simple check valve retains the pressure in the BIB system after hose separation and will provide protection against excessive opening parachute shock forces that may be exerted on the crewman during various conditions of chute inflation. A properly designed porous bladder material will allow a controlled deflation, so that following parachute opening the pilot will not be encumbered during descent nor will it degrade touchdown survivability procedures.

To protect against over pressurization and to compensate for variations in ejection altitude, an appropriate relief valve will be investigated for inclusion into the system. In general, laboratory testing has indicated that an effective inflation pressure for the prototype configurations is approximately 3 PSI with a deflation time of 5 to 7 seconds after initiation. This time interval will allow for parachute opening to occur before pressure loss for about 95 percent of all ejection cases. Location and configuration of the fill hose and fittings will be sufficiently different from the anti-'G' hose and vent suit hose and vent suit hose to prevent connection to the wrong supply line.

DEVELOPMENT HISTORY

Initial fabrication of an inflatable system into a conventional flight suit was accomplished in March 1976. This configuration consisted of two separate bladders contoured as shown in figure 1. The two bladders were joined by a

connector tube which was routed around the inside of the coverall collar. The separate bladder configuration was necessary to maintain the front zip donning capability which is still highly desirable and mandatory. As a consequence, the system requires a connection upon ingressing the seat and will consist of a pull apart plug similar to the anti-'G' or vent air connectors, but it will be of a different size to prevent connection to the wrong hose. The coverall modification was simply an addition of two stowage pockets sewn on the inside with access slots to allow installation of the inflatable bladders.

INITIAL PROTOTYPE EVALUATION - STATIC

The Navy's Maximum Performance Escape System (MPES) ejection seat was used as a test bed to conduct the preliminary subjective evaluation of the first coverall installed inflatable system. The seat was configured with a compressed air source and an accumulator/pressure release mechanism (figure 4) which allows the inertia reel and lap belt retractors to fire simulating the actual ballistic action on the seat during ejection. Through appropriate tubing, shut-off valves, and pressure reducers, the inflatable bladder system was allowed to inflate to a set of predetermined test pressures. The initial series of subjective tests of the inflatable system was conducted in conjunction with the automatic lap retraction subsystem which is a component on the MPES seat.

In all tests, the lap belt was left initially loose prior to the cinch-up action. After the cinch-up cycle, the bladders were allowed to inflate slowly by regulating a valve upstream of the pressure reducer. As the bladder pressure increased, the subjects were able to experience varying degrees of restraint force applied to their upper torso. Six different subjects were utilized to obtain subjective data such as: the effectiveness of the restraint, the peak tolerable inflation pressure, comfort, and the effect on the subjects' breathing capability. The effectivness of the restraint was determined by the subjects' inability to move forward, up, down, or sideways in the seat while inflated. All subjects experienced a total inability to move the upper torso, except for minimal side-to-side motion of the buttocks. All subjects noted the evenly distributed pressure across the torso pushing them into the seat back, with no associated discomfort.

The peak pressures that each subject was capable of tolerating within the bladders varied from 1.5 to 3.0 PSI. This variation can be attributed to: the amount of initial belt tension prior to the cinch-up/inflation cycle, personal tolerance level, and finally the fit of the MA-2 integrated torso harness and chest strap adjustment. At the point where each subject determined that they were sufficiently tight, no painful discomfort was experienced; however, all subjects were restricted in their ability to fully inhale due to the pressure exerted against the chest from the BIB. Although all subjects experienced the shallow breathing condition at their peak tolerable pressure, none felt it would cause any adverse effects for the short duration of time that they would be subjected to this condition.

After completing the first series of static testing, it was decided to reduce the size of the bladders to determine if a smaller area would also produce a sufficient degree of upper torso restraint.

The second bladder was fabricated with an extra number of ribs between the bladder walls to keep it constrained in a flatter configuration upon inflation, thereby conforming more closely to the shape of the upper torso. Another series of static tests with the second prototype model showed that this system again effectively restrained all the test subjects as in the first case. In this series of tests, the bladder pressures were all between 4.5 to 5.5 PSI, and all subjects were again restricted to shallow breathing at these levels.

Upon completion of the successful demonstration of the use of an inflatable system as a means of providing an extremely effective method for restraining and coupling the crewmember to the seat for pre-ejection positioning, additional efforts were undertaken to determine more practical configurations for providing such restraint.

VEST TYPE INFLATABLE RESTRAINT DEVELOPMENT

Although the flight suit configuration provided a convenient means for demonstrating the effectiveness of the inflatable restraint concept, it was not considered practical from an operational standpoint as the packaging element for the bladders. The flight suit is worn as an outer garment during much of the nonflight duty hours. The bladders would cause additional bulk, increase heat build-up, and subject the system to potential damage during this time.

As a consequence, an inflatable vest type garment concept was considered. This would be an easily donned light weight vest which would be worn over the flight suit and under the MA-2 Integrated Torso Harness. A number of configurations were examined and the initial one selected for fabrication and evaluation is shown in figure 2. This initial prototype was considered to be the maximum useful size and was selected to determine its effectiveness, volume requirements, inflation fill time, weight, bulk, and comfort. It was anticipated that future prototype refinements would optimize effectiveness versus size.

A 50 percentile subject was selected for developing the patterns for the BIB vest. An additional advantage of the separate vest concept is that it can be contoured more to the body to provide better retention and load distribution, rather than when constrained to the geometry of the flight suit coverall which only allows limited variations in shape due to the zipper down the front and interference with seams and pockets. It also allows the vest to be made in one piece rather than with the two separate bladders as required for use in the flight suit.

As seen in figure 2, the vest has convenient straps that are adjustable with velcro fasteners. The vest also simplifies fabrication and negates the need to modify the flight suit. The first vest prototype was completed in April 1978 and was used for fit studies, volume measurements, manual inflation testing, comfort, donning and removing studies, and fabrication techniques. As a result of this evaluation, a second prototype vest was fabricated which included many beneficial changes, especially in shape and fabrication techniques. This second vest model was selected as suitable for further testing.

EJECTION TOWER TESTING

An ejection tower test program was conducted utilizing the second vest prototype. The objective of the testing was to determine if there was any improvement in the degree of restraint during ejection with the inflatable device over current operational systems. The approach was to conduct a comparative analysis between an inflatable vest in conjunction with the MA-2 an inflatable vest and head support bladder in conjunction with the MA-2 harness and the MA-2 harness alone.

Instrumentation

The basis for comparing the difference in performance was the acquisition and analysis of instrumentation data such as:

- 1 rate gyro in the dummy chest
- 1 horizontal accelerometer in the dummy chest
- 1 vertical accelerometer in the dummy chest
- 1 vertical accelerometer in the dummy head
- 1 accelerometer on the catapult gun
- 1 rate gyro in the dummy head
- 1 pressure transducer in the BIB
- 1 pressure transducer in the neck bladder
- 1 horizontal accelerometer in the dummy head

Photographic Coverage

Photographic coverage consisted of:

- 2-400 FPS cameras mounted stationary on the ground to record the side view of seat motion up the rails to 120 inches up the rails
- Still coverage was obtained to document and verify pretest and post test conditions.

Equipment

The equipment required was:

- 1 body inflatable bladder
- 1 neck support bladder
- A Martin-Baker ejection seat utilizing the standard NAMC 40-inch stroke catapult.
- A 50 percentile dummy.

Test Program Outline

Funding limitations and strict scheduling of Ejection Tower "on-time" permitted only a total of 8 firings, scheduled as follows:

- Three control tests utilizing the standard AA-2 integrated torso harness in the conventional manner
- Three tests utilizing the vest type BIB under the MA-2 harness
- Two tests utilizing the BIB and the neck support bladder.

Test Set-Up

- All tests were conducted with a 50-percentile dummy positioned in a Martin-Baker ejection seat and utilizing the standard NAMC catapult.
- The dummy was marked with appropriate target points to measure displacement from a preselected stationary base location. (figure 5).
- The dummy restraint system was snug to simulate normal flight conditions.
- The inertia reel was fully retracted and locked.
- The dummy was repositioned in the seat in an identical manner prior to each test, using the target points on the dummy and fixed reference points on the ejection tower.
- The dummy was dressed with only the MA-2 harness. No boots, helmets, survival gear or coveralls were used during the testing.
- The inflatable vest and neck bladder support were inflated to the same pressure, prior to firing, for all tests in which they were used.
- The BIB and neck support collar pressures were monitored within seconds prior to each test firing to assure reproducibility of each test series.

RESULTS AND CONCLUSIONS

Table I is a compilation of all the recorded peak values obtained from the limited test study. The curves shown in appendices A through C were plotted from the digitized data. Figures A-1 through A-5 of appendix A are plots of torso angular displacement versus time for each of the tests conducted with the BIB system alone and the BIB system with the neck collar configurations. These curves also show a plot of the average standard configuration or control series superimposed for easy comparison. All of these plots show a smaller angular displacement than the average standard control configuration and show the peak values occurring much earlier. Also, very much in evidence is a rapid decrease in amplitude, simulating a decaying sinusoidal response. This response is obviously a characteristic of the air bladder; its effect on system performance or safety aspect is not immediately discernible.

Only live testing will provide a subjective evaluation. These tests do, however, indicate that the dummy was further back in the seat during the ejection sequence.

The curves shown in figures B-1 through B-5 of appendix B are plots of the torso rate gyro versus time. Each test with the BIB alone and with the BIB plus neck collar are again plotted together with the average control tests superimposed for easy reference and comparison. Also superimposed is a plot of the vertical catapult acceleration for additional reference. From these plots, as well as from the peak values shown in table I, it is significant to note that the greatest reduction in torso rotation occurs with the BIB in combination with the neck support collar. This is consistent with previous data which showed that the torso response is affected by head motion. The data clearly shows that the torso is moving at a much slower rate with either the BIB or BIB plus neck collar at the time of peak catapult acceleration, compared to the control or standard configuration. Also, the BIB plus neck collar series shows the torso rate peaking much earlier than the BIB only or the standard configuration, indicating a more stable condition during catapult onset. Referring back to table I, the horizontal torso acceleration series shows an average 44 percent reduction in peak acceleration with the inflatable bladder vest system compared to the standard configuration. Also from table I, it was determined that 45 percent reduction occurred in the average torso angular velocity with the BIB only configuration as compared with the average velocity with the standard configuration.

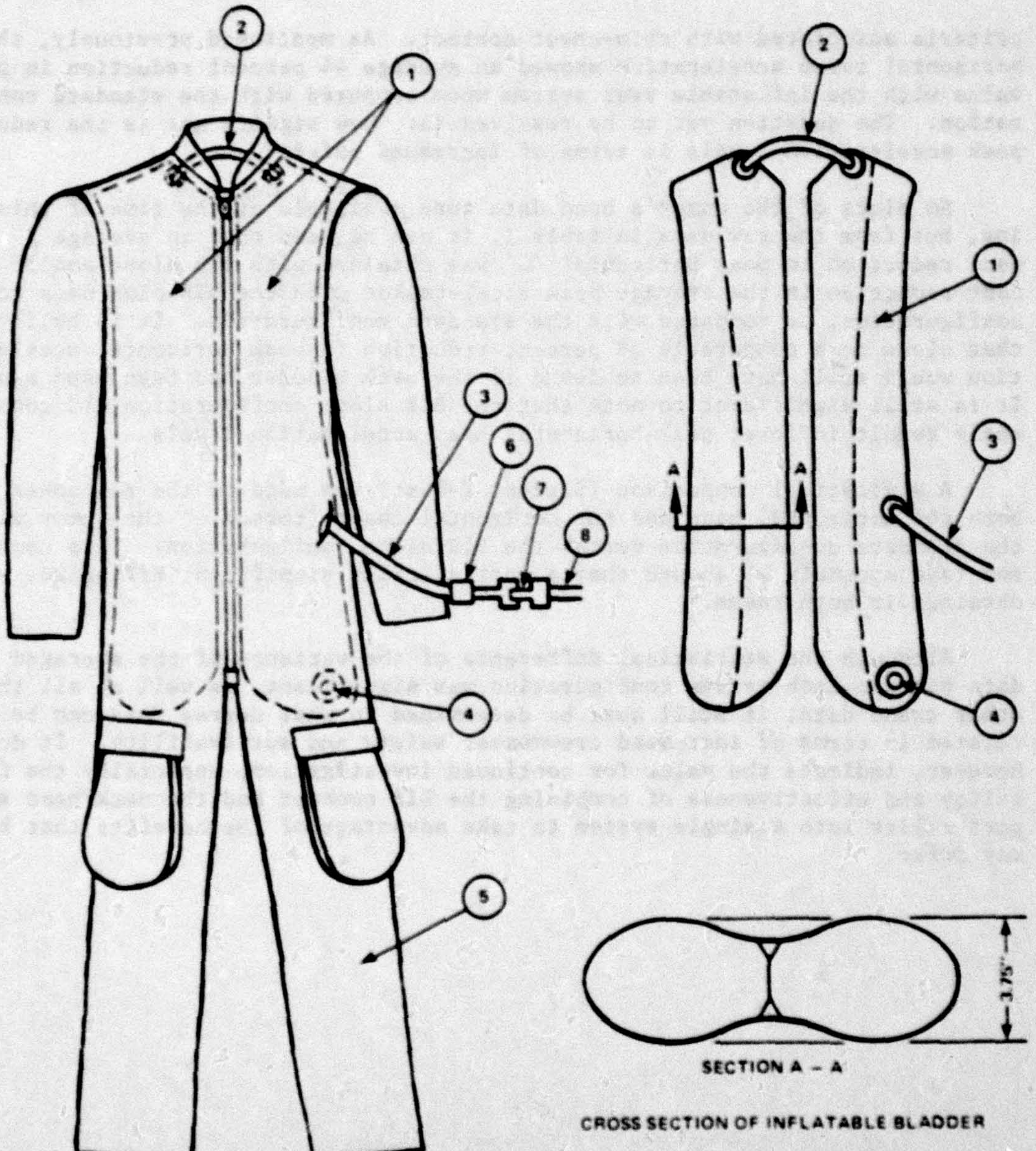
The curves shown in figures C-1 through C-5 of appendix C are plots of horizontal torso acceleration versus time. Each BIB only test (No's 4, 5 and 6) and BIB plus neck support collar test (No's 7 and 8) are plotted with the average standard configuration series superimposed as well as the catapult gun acceleration trace for reference and easy comparison. Although the BIB only configuration shows a reduction in peak torso acceleration, a more significant change occurs in the horizontal component of the head acceleration. The BIB plus neck collar shows very little difference in the magnitude of the horizontal torso acceleration, but does show a more significant change in the horizontal head component as compared to both the standard and BIB only configuration. The addition of the neck collar also has an effect on the shape of the horizontal acceleration signature, because the neck collar prevents the dummy's chin from 'bottoming out' on the dummy's chest. There is certainly more significance in terms of head injury, since there is no chest injury data

criteria associated with chin-chest contact. As mentioned previously, the horizontal torso acceleration showed an average 44 percent reduction in peak value with the inflatable vest system when compared with the standard configuration. The question yet to be resolved is: how significant is the reduced peak acceleration levels in terms of increased safety?

No plots of the dummy's head data were available at the time of this writing, but from the raw data in table I, it can be seen that an average 37 percent reduction in peak horizontal 'G' was obtained with BIB alone and 58 percent reduction in the average peak acceleration with the BIB plus neck collar configuration, as compared with the standard configuration. It is believed that close to a comparable 58 percent reduction in peak horizontal acceleration would still have been achieved if the neck bladder had been used alone. It is still significant to note that the BIB alone configuration did consistently result in lower peak horizontal head acceleration levels.

A statistical comparison (Student T-Test) was made of the responses of both the horizontal head and the horizontal chest (torso) of the dummy with the standard configuration versus the BIB alone configuration. This comparison (see appendix D) showed that a statistically significant difference was obtained in both cases.

Although the statistical difference of the variance of the averaged test data between each series configuration was significant, as well as all the other trend data, it still must be determined to what degree this can be correlated in terms of increased crewmember safety and survivability. It does, however, indicate the value for continued investigation, especially the feasibility and effectiveness of combining the BIB concept and the neck/head support collar into a single system to take advantage of the benefits that both may offer.



1. INFLATABLE BLADDERS
2. CONNECTOR TUBE
3. INFLATION HOSE INLET
4. PRESSURE RELIEF VALVE
5. COVERALLS
6. CHECK VALVE
7. CONNECTOR/PULL APART FITTING
8. PRESSURE INLET HOSE

FIGURE 1 - Inflatable Bladder Installed In Flight Suit

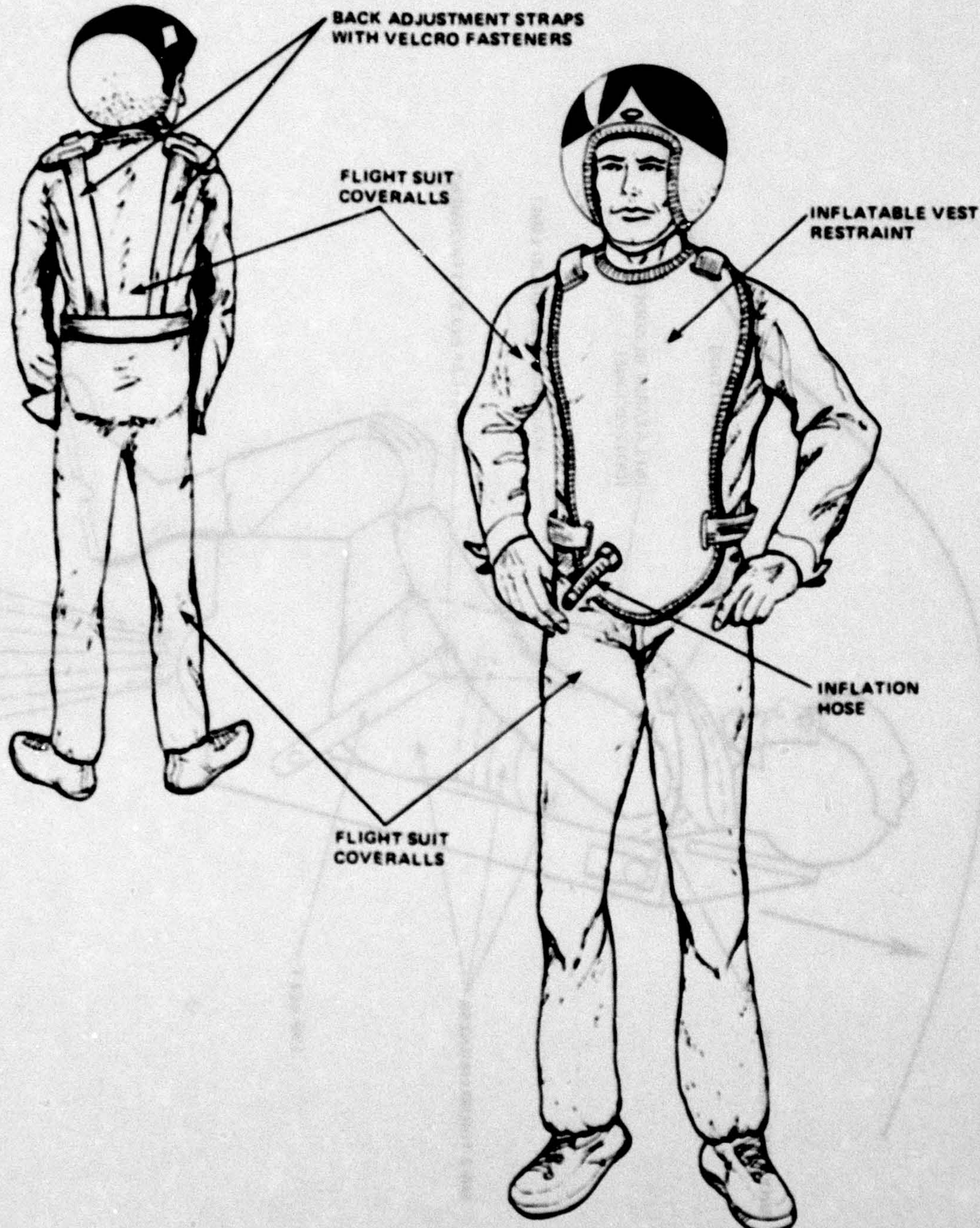


FIGURE 2 - BIB Vest Configuration

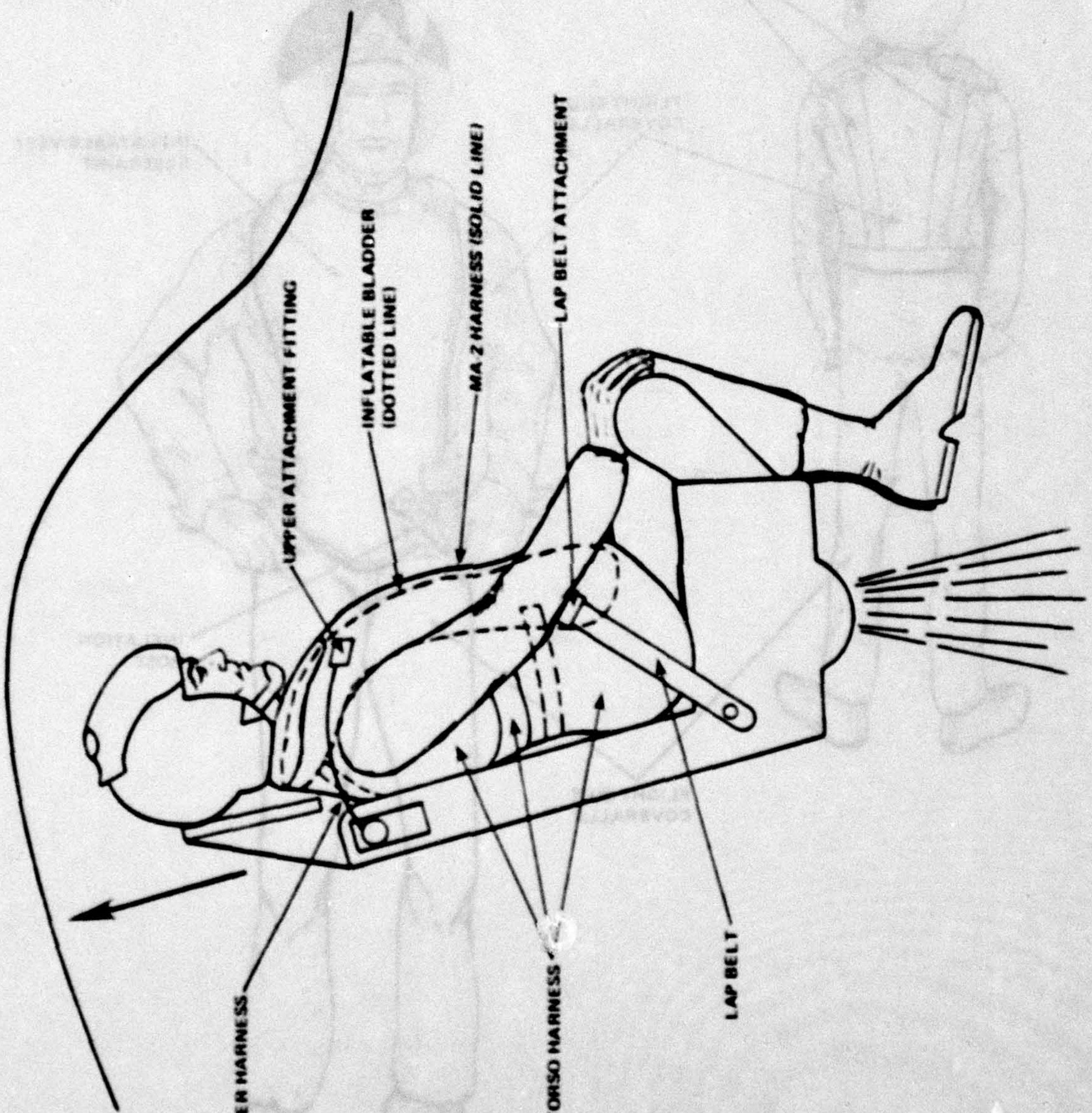


FIGURE 3 - Depiction Of Optimal Ejection Position

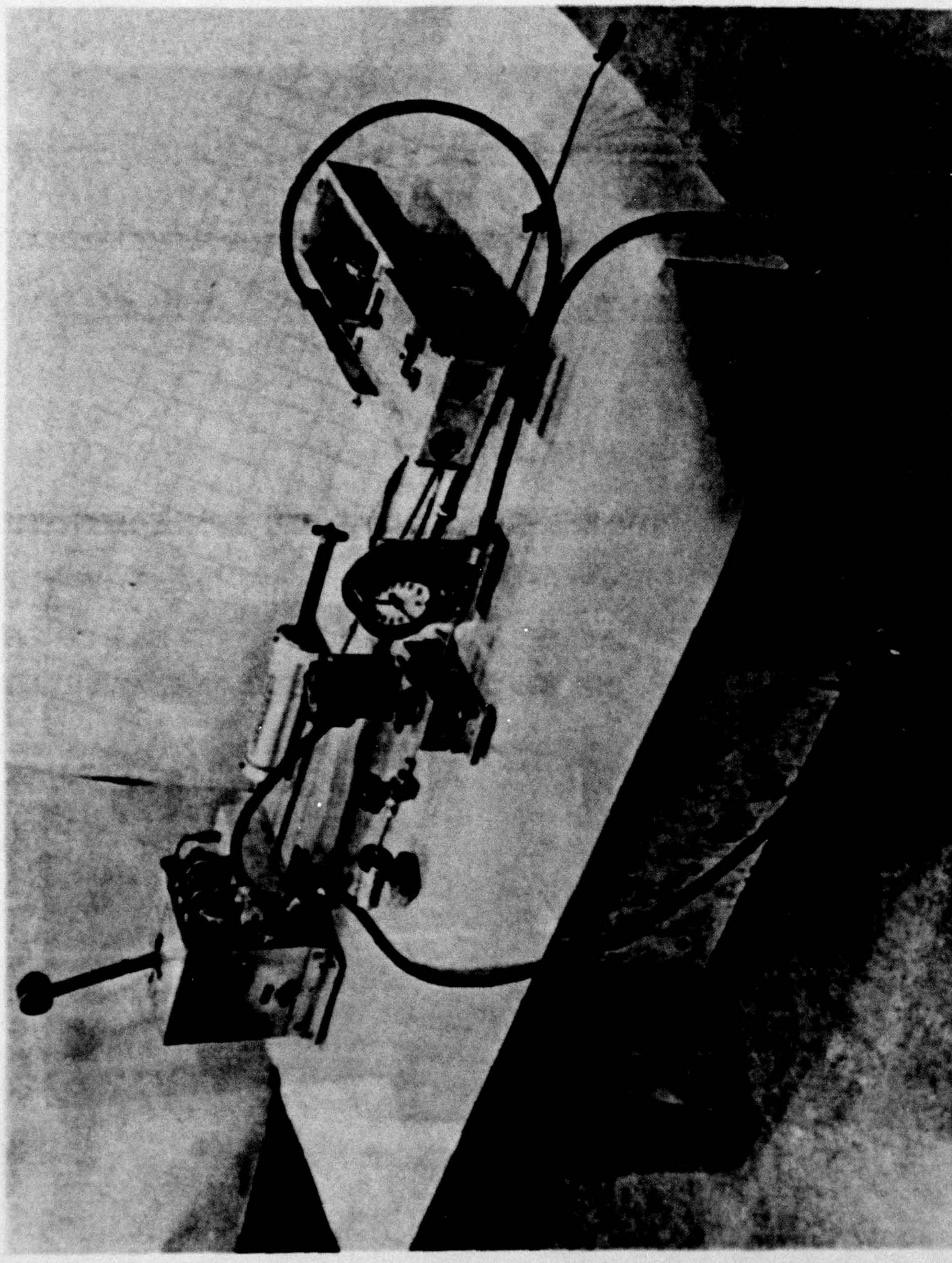


FIGURE 4 - Variable Accumulator/Pressure Release Device

FIGURE 5 - Dummy Pretest Set Up - Side View

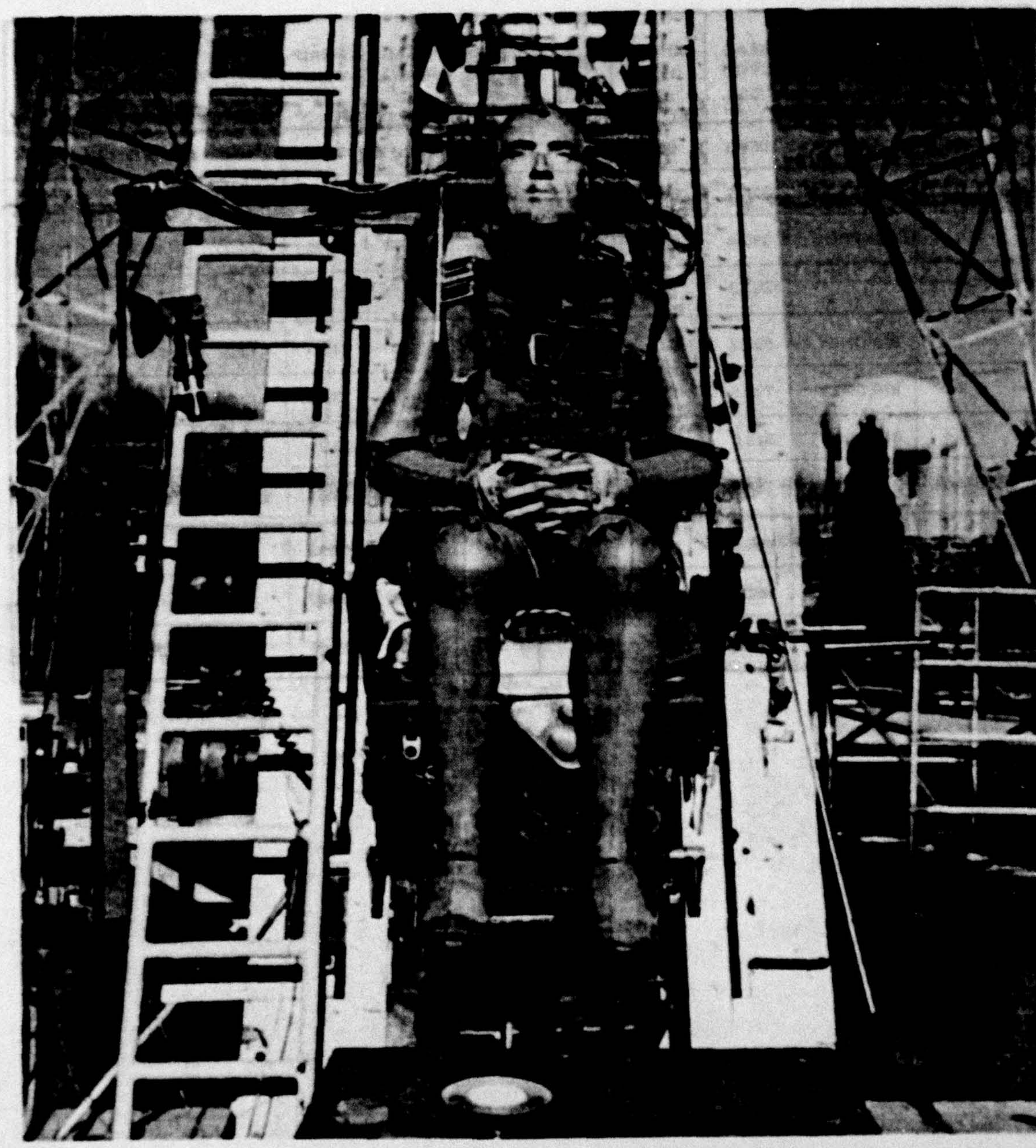


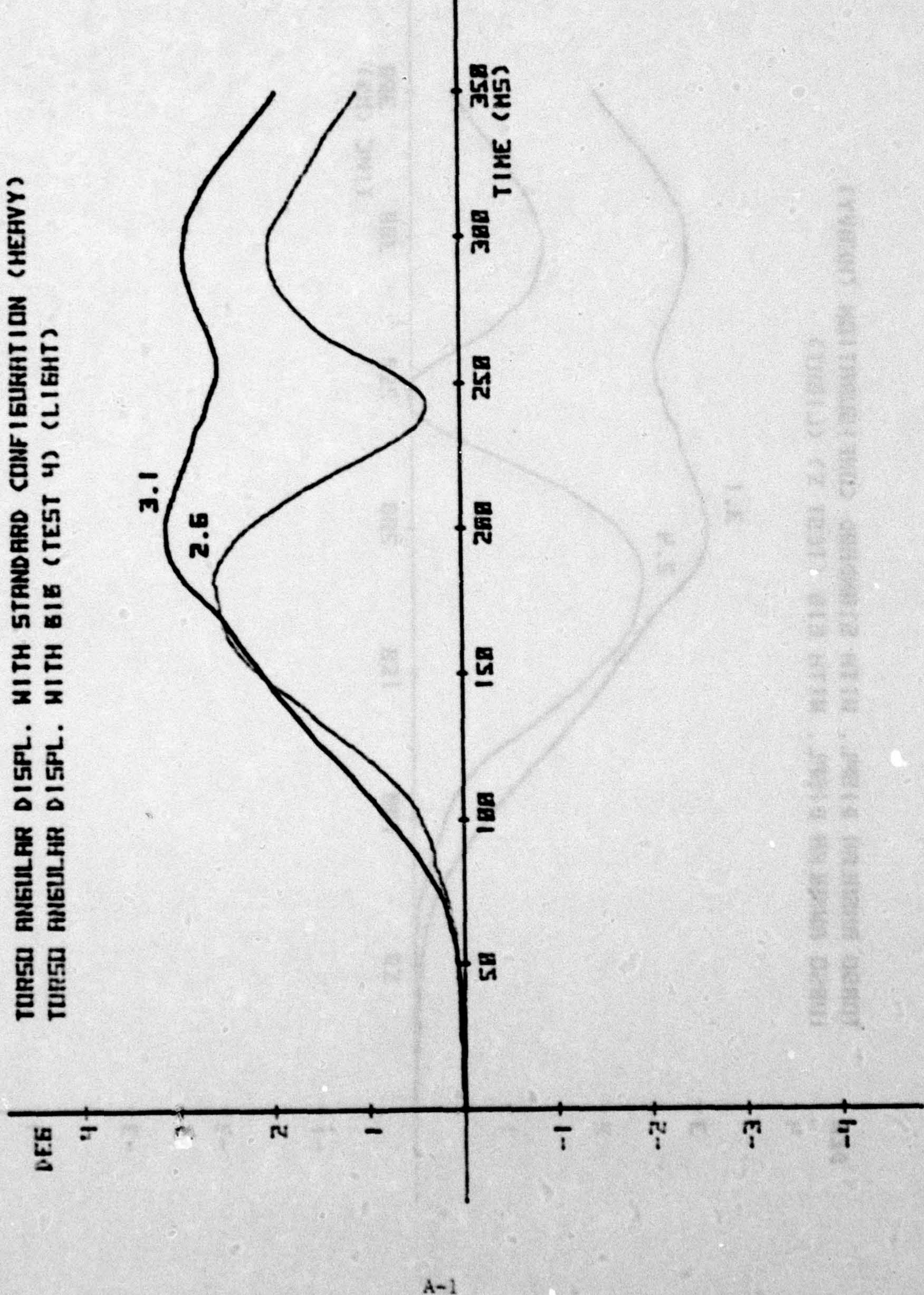
FIGURE 6 - Dummy Pretest Set Up - Front View

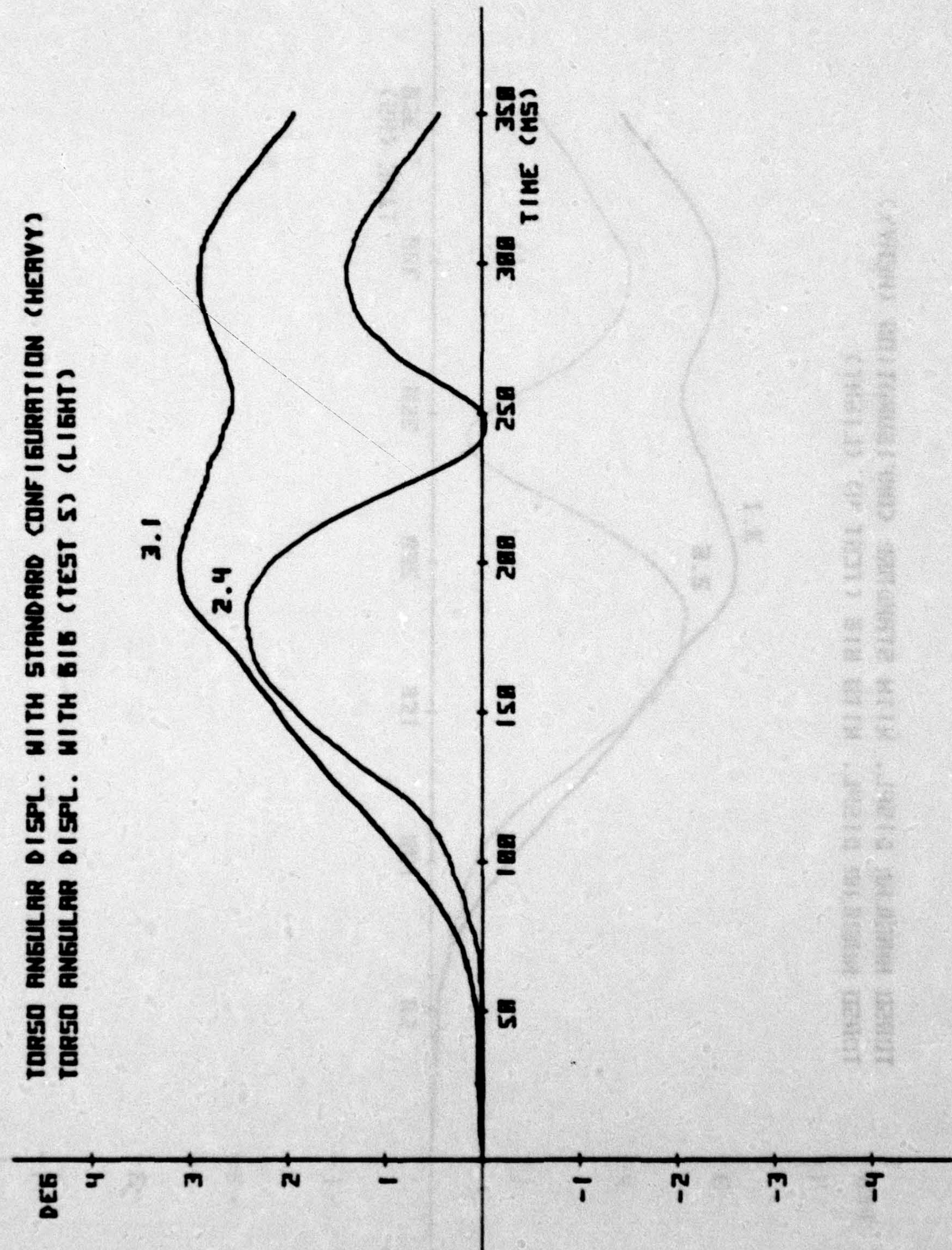
TABLE I - TEST SERIES INSTRUMENTATION DATA OF PEAK VALUES

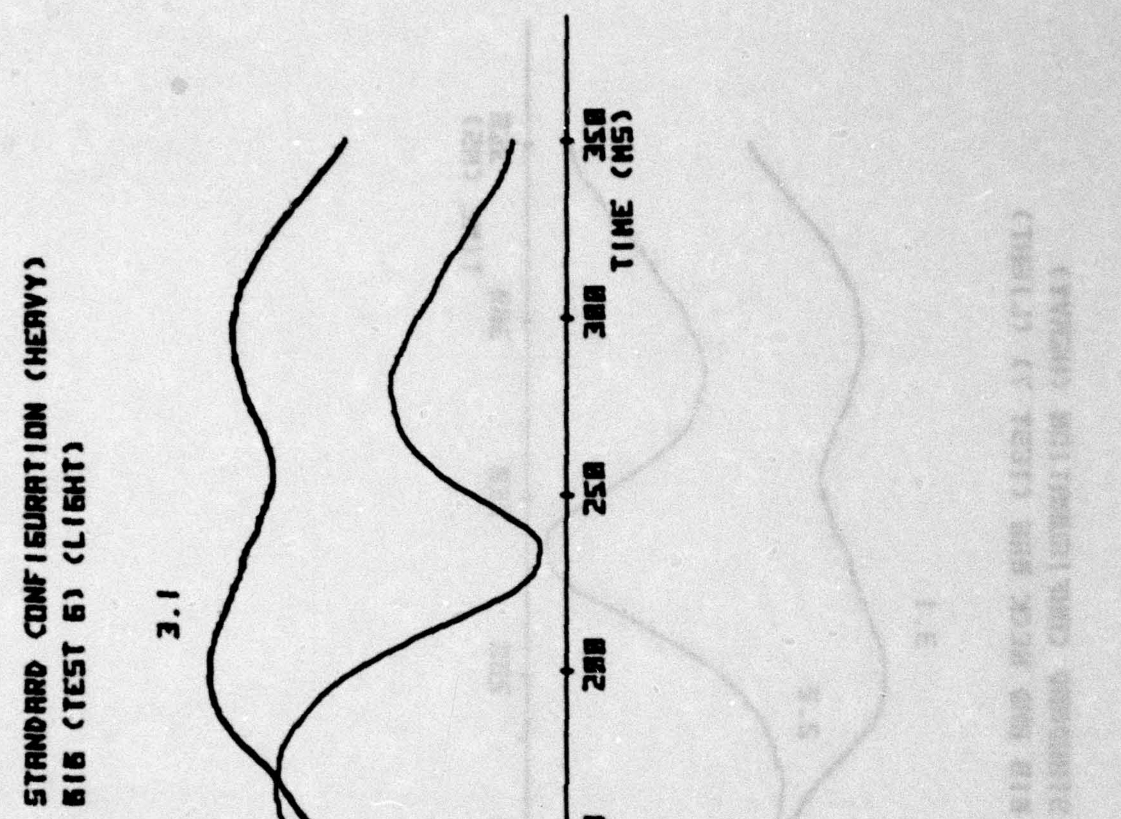
	TEST NO.	CONFIG.	HEAD GYRO °/SEC.	CHEST GYRO °/SEC.	NECK BAG	BIB PRESS PSI	HEAD HORIZ. 'G'	HEAD VERT. 'G'	CHEST HORIZ. 'G' (TORSO)	CHEST VERT. 'G' (TORSO)	CATAP. 'G'
A	1	CONTROL	1068.9	60.0	NO	0	72.11	26.09	16.23	13.0	12.1
A	2	CONTROL	1322.6	55.96	NO	0	93.8	26.79	16.94	13.85	12.77
A	3	CONTROL	1395.4	106.1	NO	0	98.63	25.96	24.27	16.36	13.46
	AVERAGE		1262.3	74			88.18	26.28	19.1	14.4	12.78
B	4	BIB ONLY	697.7	32.2	NO	4.3	49.8	21.6	10.2	13.94	12.93
B	5	BIB ONLY	783.5	43.9	NO	4.3	54.72	23.00	10.28	13.57	12.29
B	6	BIB ONLY	813.6	46.80	NO	4.3	61.30	20.2	11.8	15.00	12.85
	AVERAGE		764.93	40.96			55.27	21.61	10.76	14.17	12.56
C	7	BIB & NECK	455.0	32.19	3.83	4.3	39.96	25.93	9.9	14.5	13.4
C	8	BIB & NECK	452.0	34.89	3.88	4.3	34.56	26.97	10.9	14.54	13.54
	AVERAGE		453.5	33.54			37.26	26.45	10.4	14.5	13.47

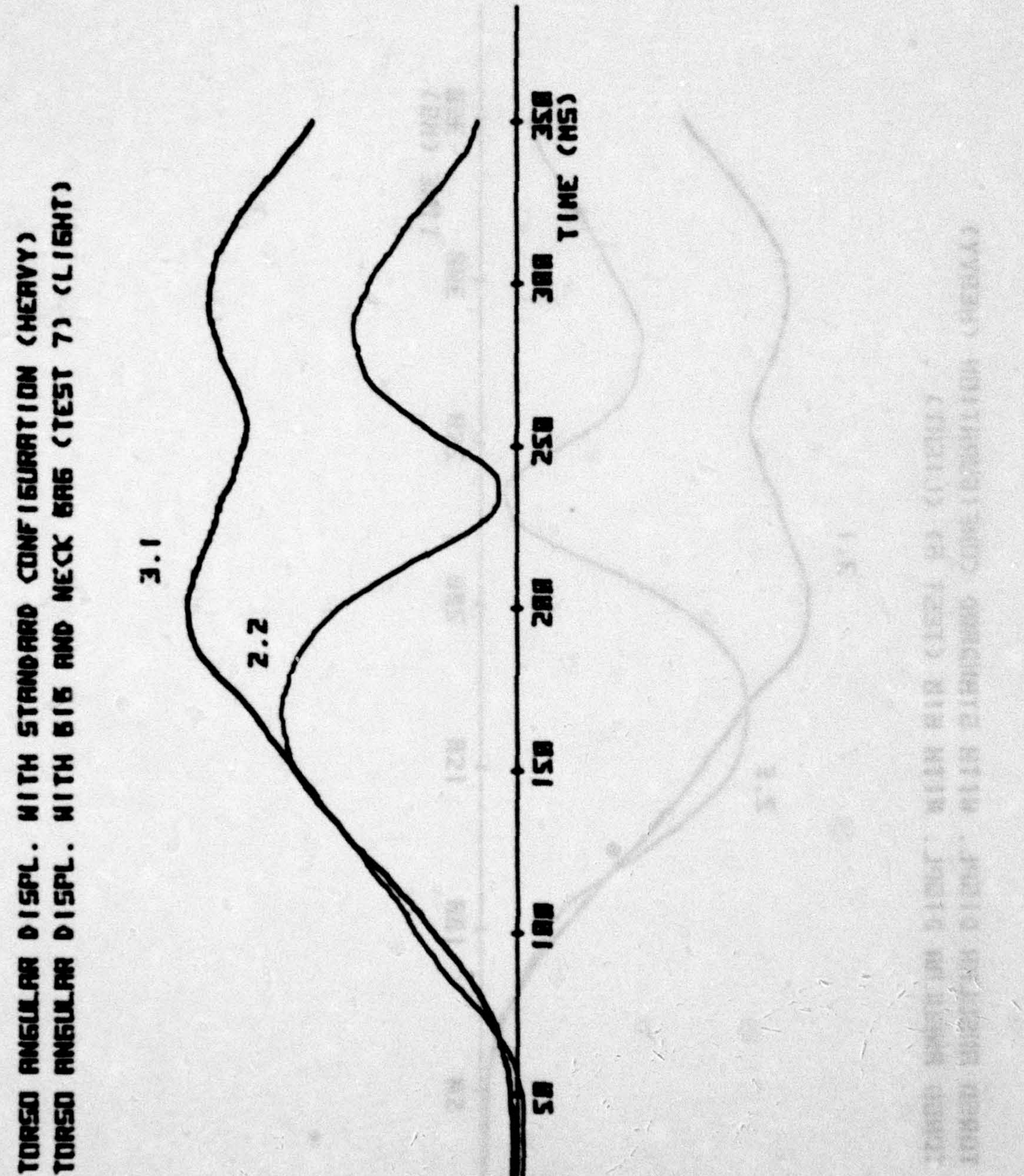
APPENDIX A

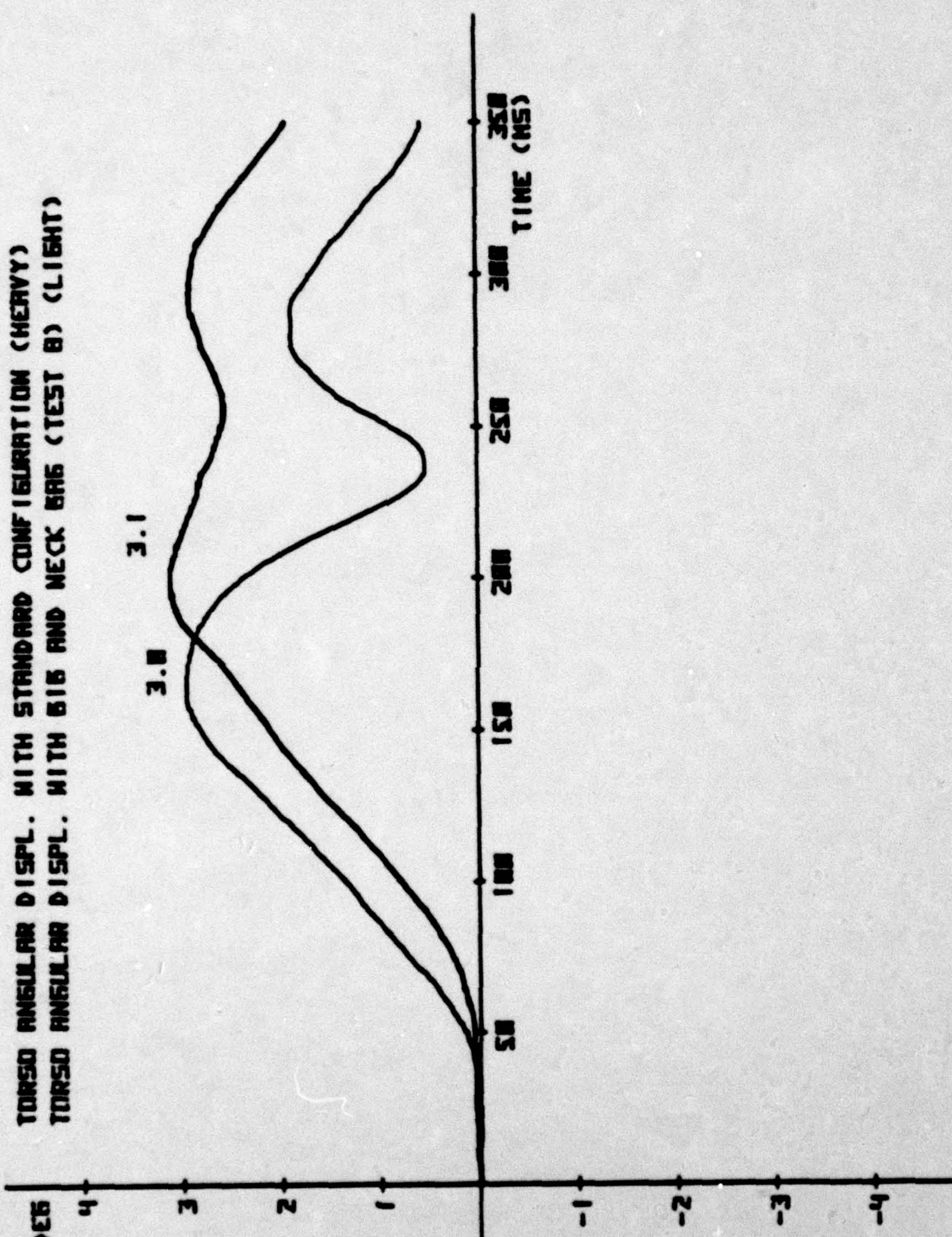
PLOTS OF DUMMY TORSO ANGULAR DISPLACEMENT


TORSO ANGULAR DISPL. WITH STANDARD CONFIGURATION (HEAVY)
TORSO ANGULAR DISPL. WITH BIB (TEST 4) (LIGHT)
DEG
4
3
2
1
-1
-2
-3
-4
50
100
150
200
250
300
350
TIME (MS)
3.1
2.6


TORSO ANGULAR DISPL. WITH STANDARD CONFIGURATION (HEAVY)
TORSO ANGULAR DISPL. WITH BIB (TEST 5) (LIGHT)
DEG
4
3
2
1
-1
-2
-3
-4
50
100
150
200
250
300
350
TIME (MS)
3.1
2.4

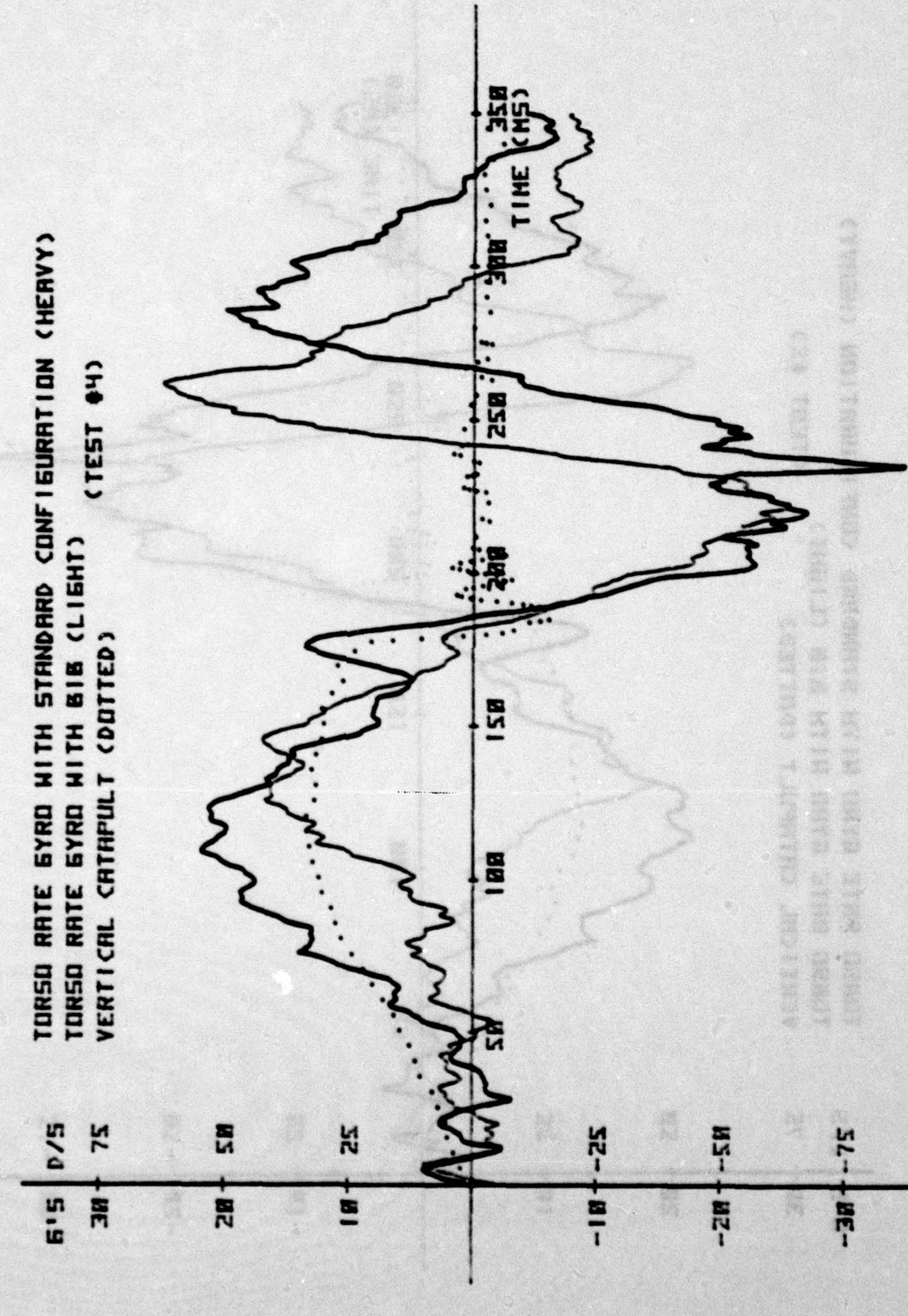

TORSO ANGULAR DISPL. WITH STANDARD CONFIGURATION (HEAVY)
TORSO ANGULAR DISPL. WITH BIB (TEST 6) (LIGHT)
3.1
2.5
DEG
4
3
2
1
-1
-2
-3
-4
50
100
150
200
250
300
350
TIME (MS)

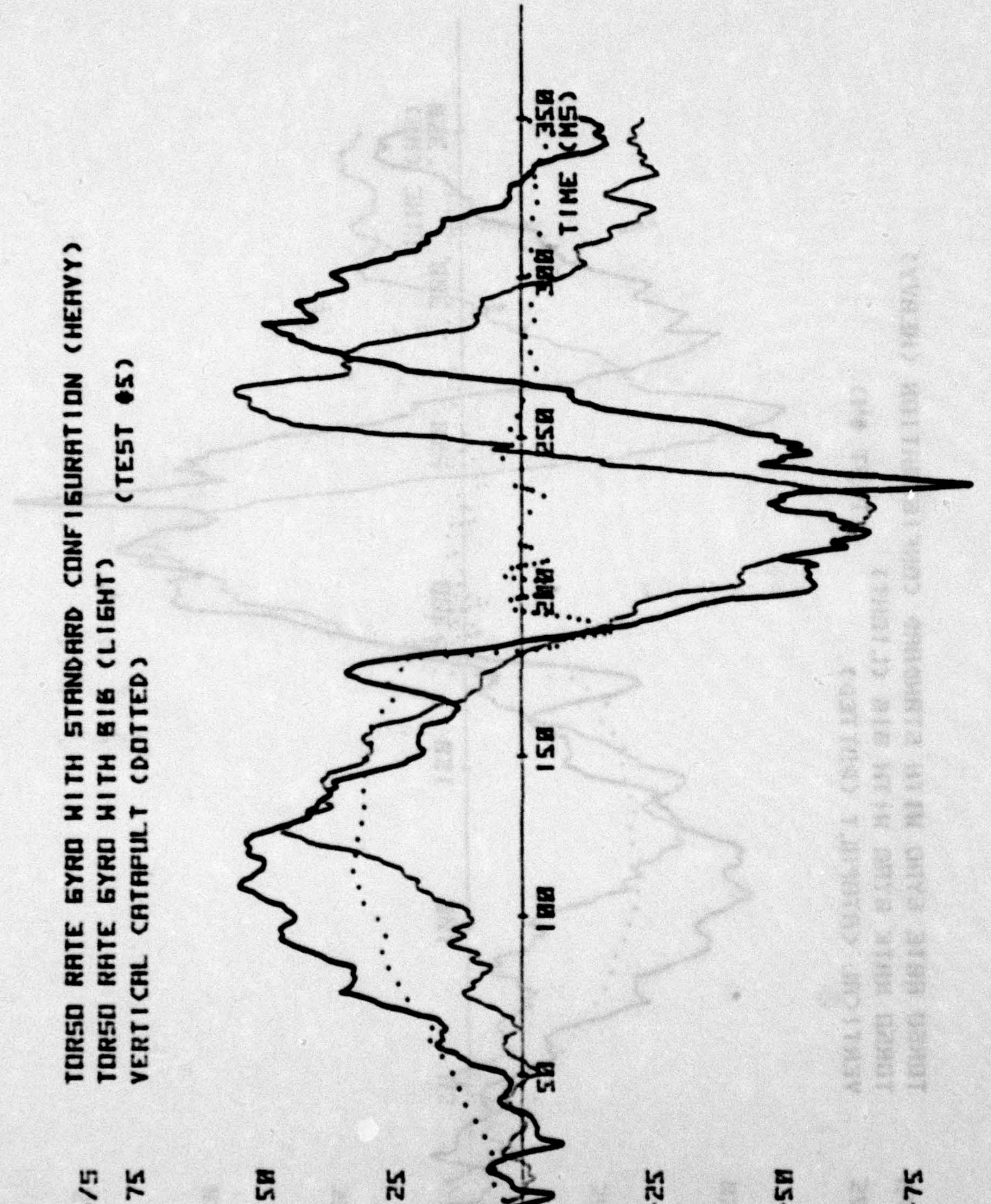

TORSO ANGULAR DISPL. WITH STANDARD CONFIGURATION (HEAVY)
TORSO ANGULAR DISPL. WITH BIG AND NECK BAG (TEST 7) (LIGHT)
3.1
2.2
TIME (MS)
50
100
150
200
250
300
350
DEG
4
3
2
1
-1
-2
-3
-4

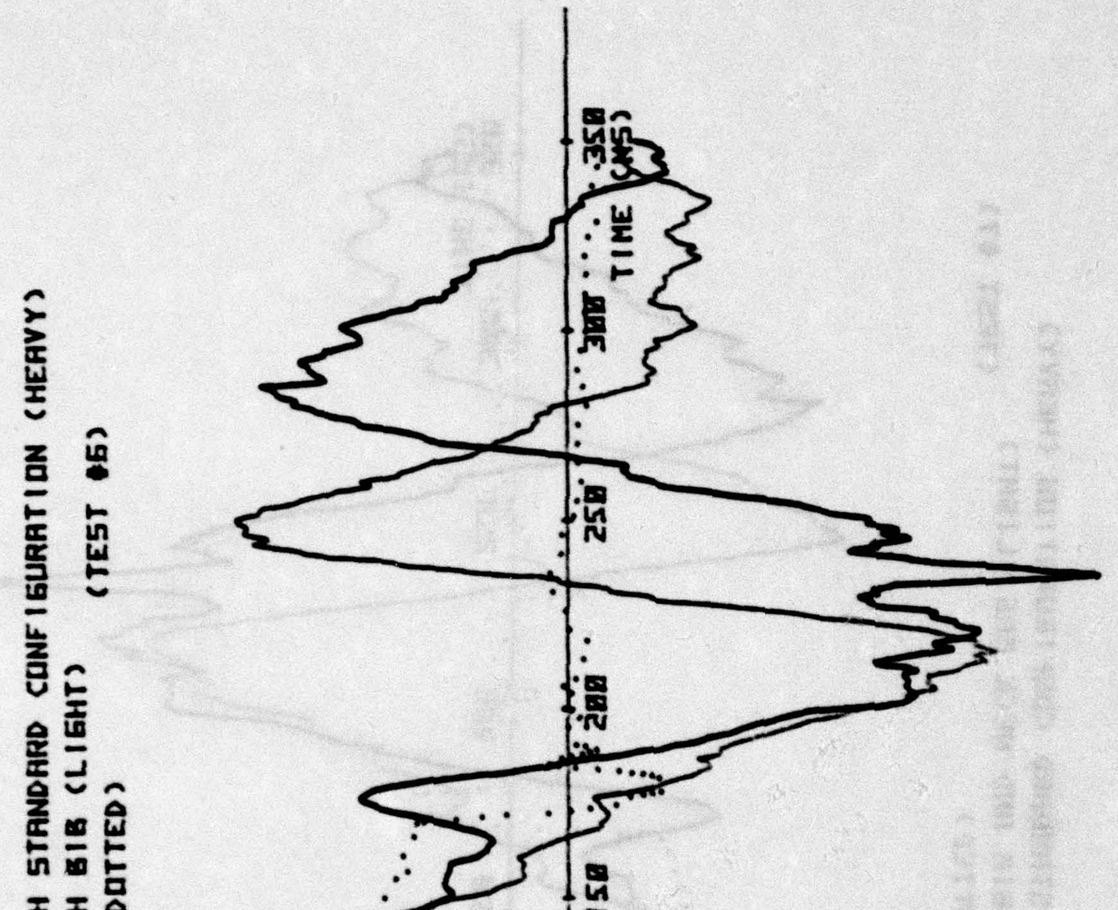

TORSO ANGULAR DISPL. WITH STANDARD CONFIGURATION (HEAVY)
TORSO ANGULAR DISPL. WITH BIB AND NECK BAG (TEST B) (LIGHT)
DEG
4
3
2
1
-1
-2
-3
-4
3.1
3.0
50
100
150
200
250
300
350
TIME (MS)

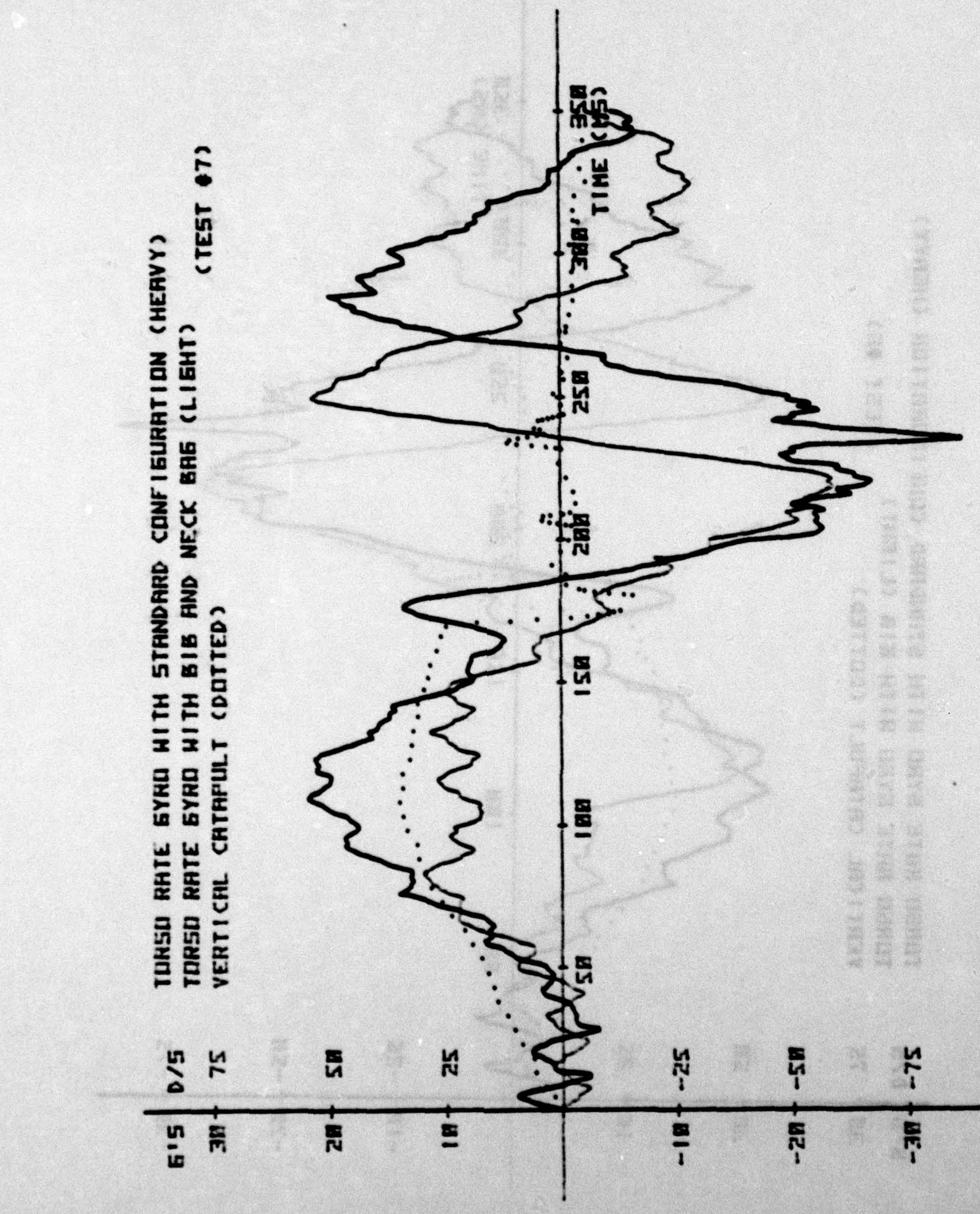
APPENDIX B

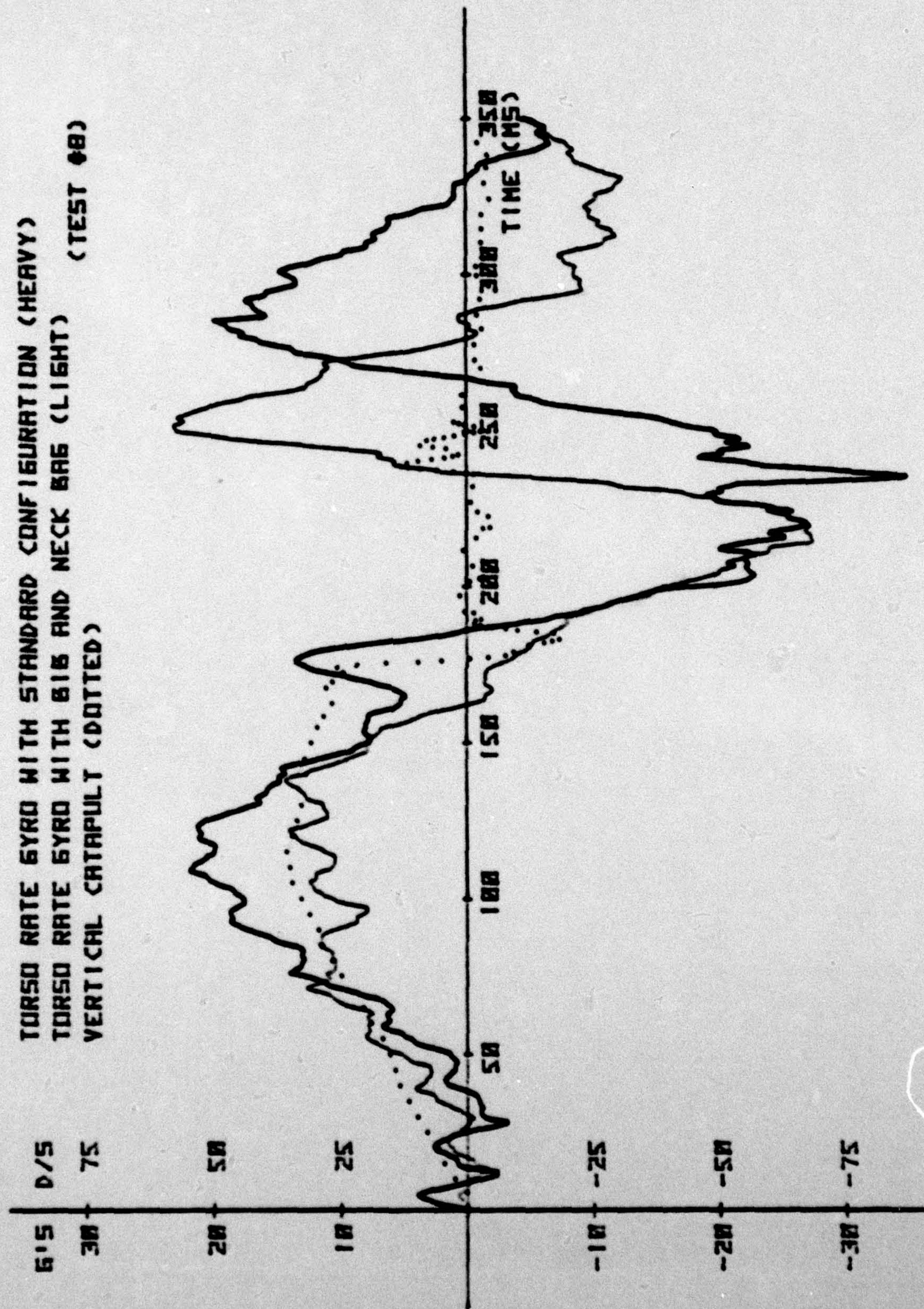
PLOTS OF TORSO RATE GYRO


TORSO RATE GYRO WITH STANDARD CONFIGURATION (HEAVY)
TORSO RATE GYRO WITH BIB (LIGHT)
(TEST #4)
VERTICAL CATAPULT (DOTTED)
G'S
D/S
30
75
20
50
10
25
-10
-25
-20
-50
-30
-75
50
100
150
200
250
300
350
TIME (MS)


TORSO RATE GYRO WITH STANDARD CONFIGURATION (HEAVY)
TORSO RATE GYRO WITH BIB (LIGHT)
VERTICAL CATAPULT (DOTTED)
(TEST #5)
G'S
D/S
TIME (MS)
50
100
150
200
250
300
350
30
20
10
-10
-20
-30
75
50
25
-25
-50
-75

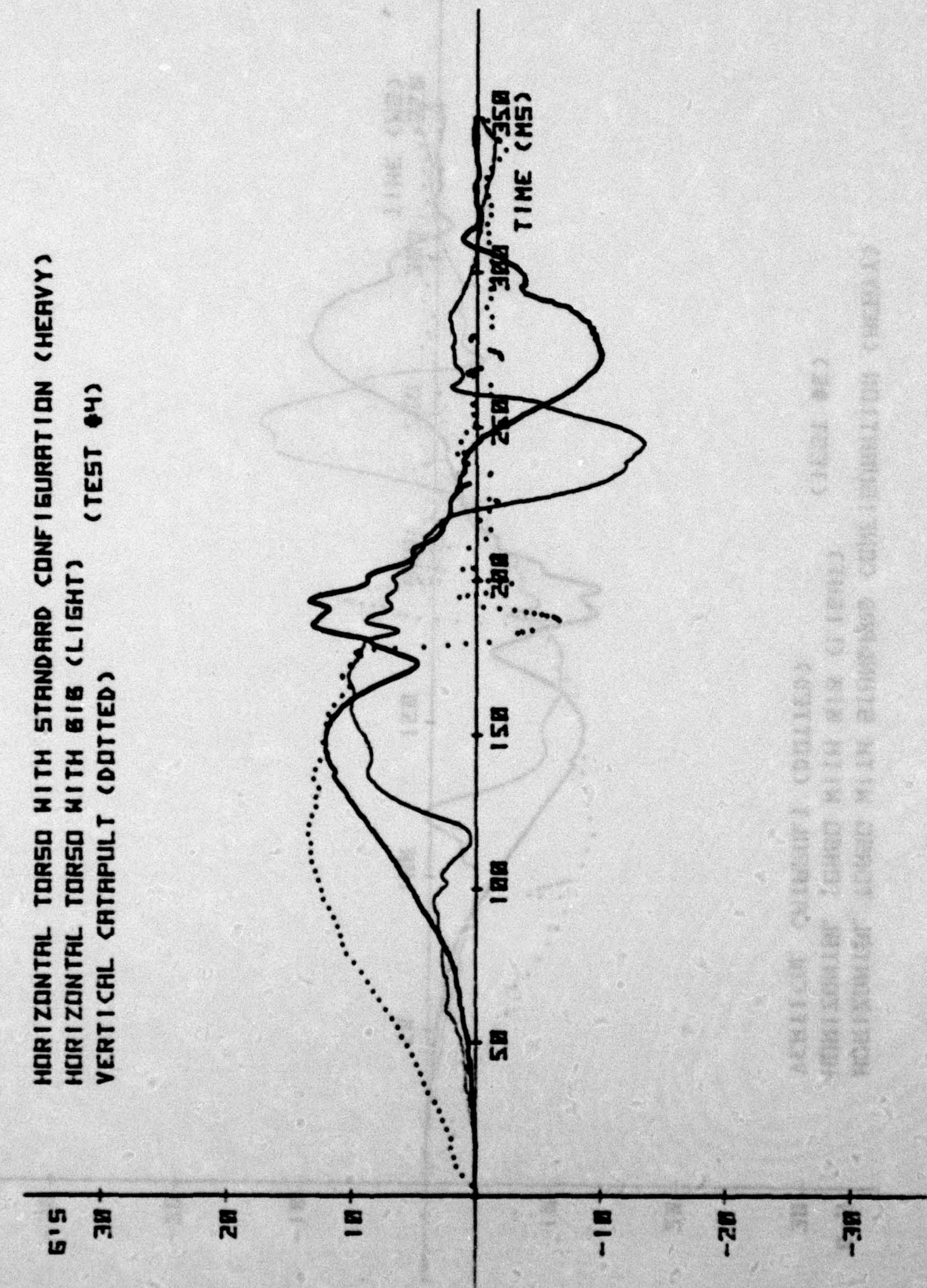

TORSO RATE GYRO WITH STANDARD CONFIGURATION (HEAVY)
TORSO RATE GYRO WITH BIB (LIGHT)
(TEST #6)
VERTICAL CATAPULT (DOTTED)
G'S
D/S
30
75
20
50
10
25
-10
-25
-20
-50
-30
-75
50
100
150
200
250
300
350
TIME (MS)

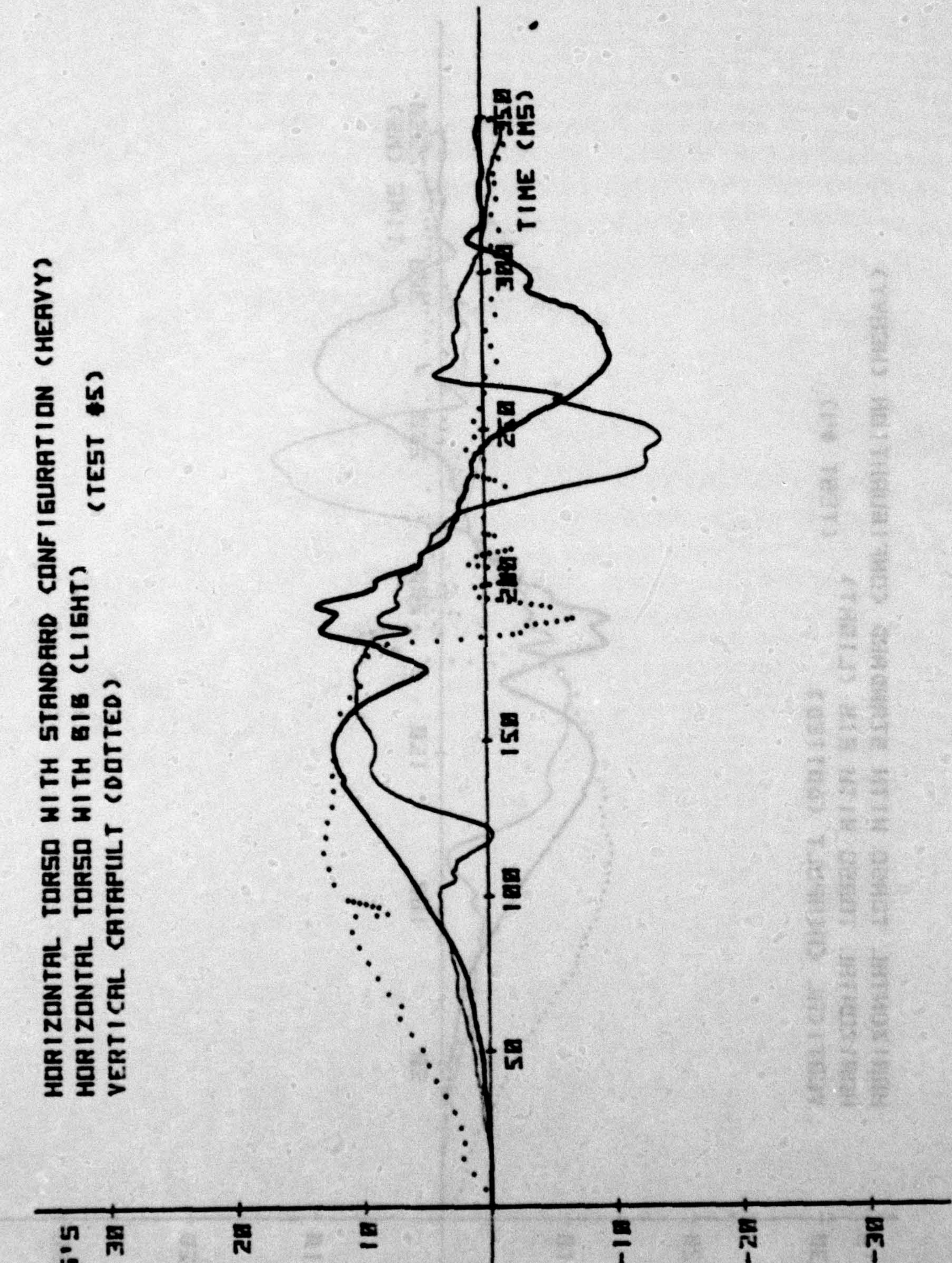

TORSO RATE GYRO WITH STANDARD CONFIGURATION (HEAVY)
TORSO RATE GYRO WITH BIB AND NECK BAG (LIGHT)
VERTICAL CATAPULT (DOTTED)
(TEST #7)
G'S
D/S
30
75
20
50
10
25
-10
-25
-20
-50
-30
-75
50
100
150
200
250
300
350
TIME (MS)

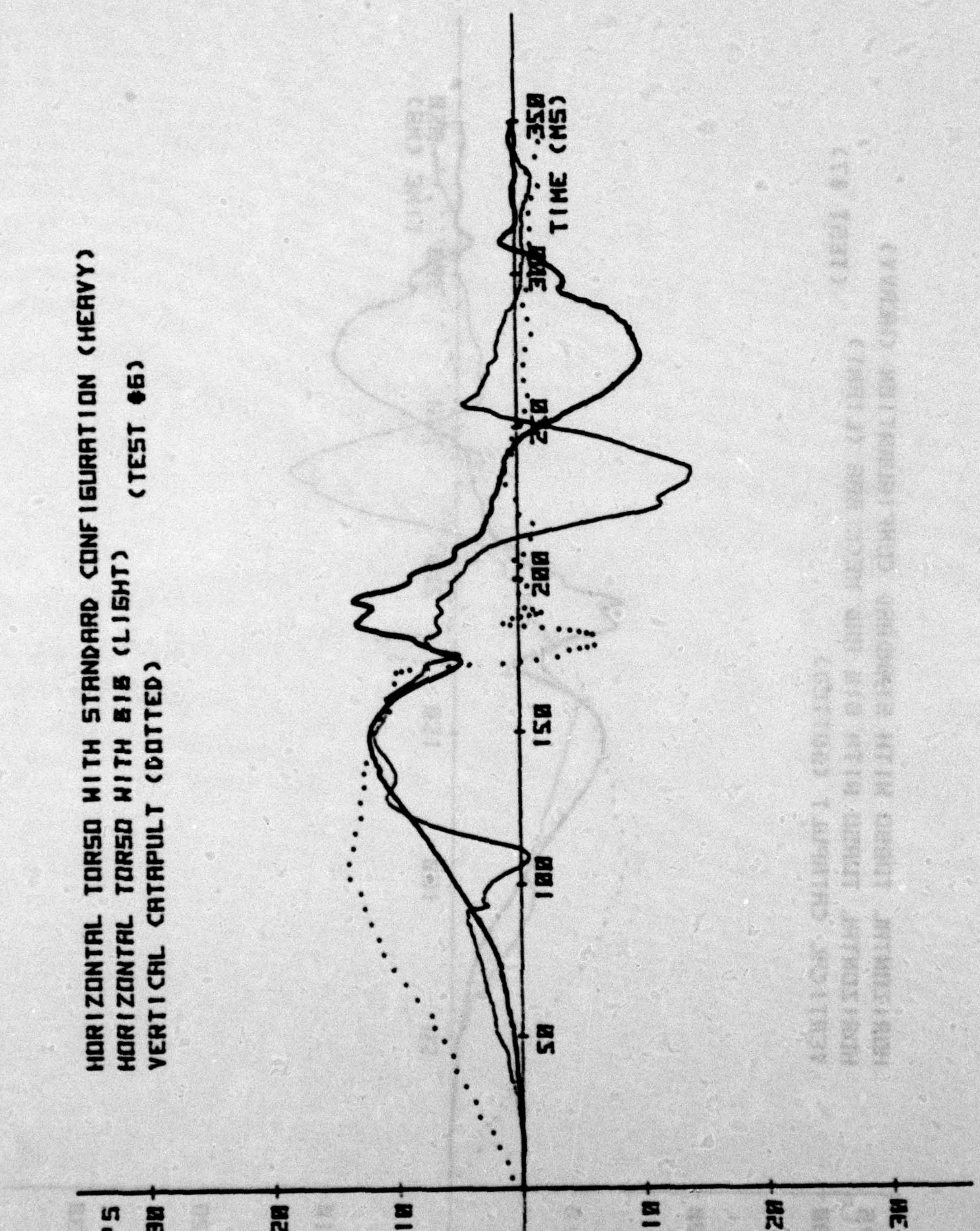

TORSO RATE GYRO WITH STANDARD CONFIGURATION (HEAVY)
TORSO RATE GYRO WITH BIB AND NECK BAG (LIGHT)
VERTICAL CATAPULT (DOTTED)
(TEST #8)
G'S
D/S
30
75
20
50
10
25
-10
-25
-20
-50
-30
-75
50
100
150
200
250
300
350
TIME (MS)

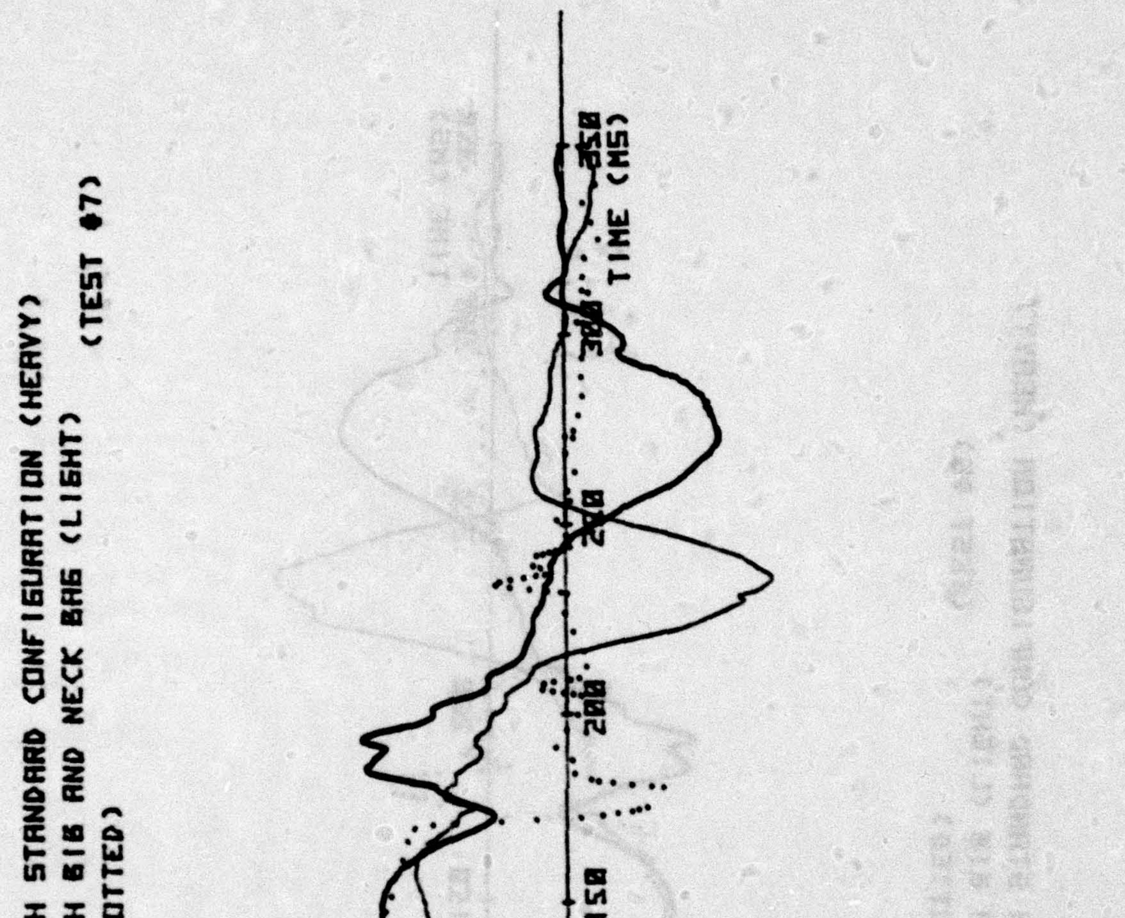
APPENDIX C

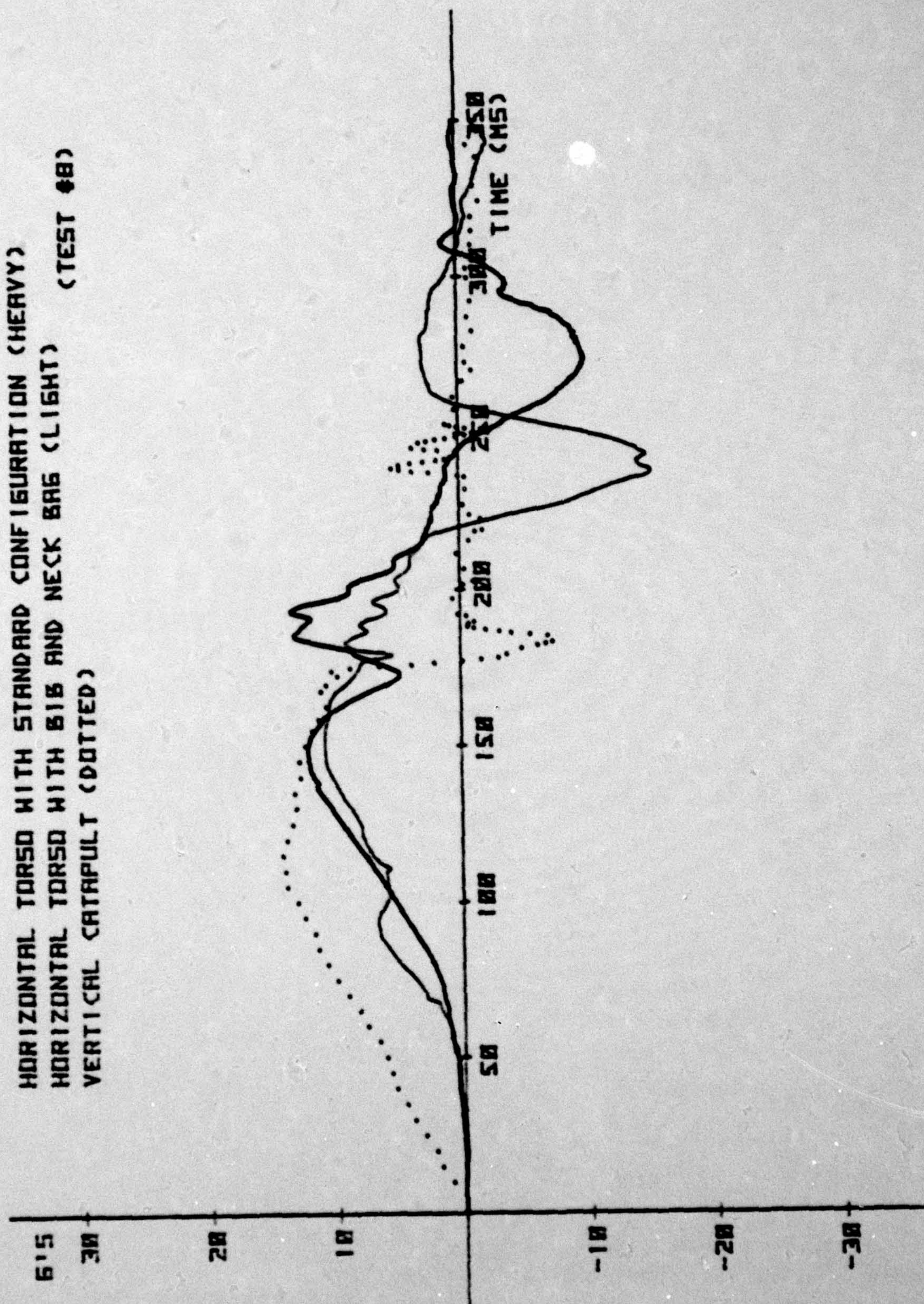
PLOTS OF HORIZONTAL ACCELERATION (TORSO)


HORIZONTAL TORSO WITH STANDARD CONFIGURATION (HEAVY)
HORIZONTAL TORSO WITH BIB (LIGHT) (TEST #4)
VERTICAL CATAPULT (DOTTED)
G'S
30
20
10
-10
-20
-30
50
100
150
200
250
300
350
TIME (MS)


HORIZONTAL TORSO WITH STANDARD CONFIGURATION (HEAVY)
HORIZONTAL TORSO WITH BIB (LIGHT)
(TEST #5)
VERTICAL CATAPULT (DOTTED)
G'S
30
20
10
-10
-20
-30
50
100
150
200
250
300
350
TIME (MS)


HORIZONTAL TORSO WITH STANDARD CONFIGURATION (HEAVY)
HORIZONTAL TORSO WITH BIB (LIGHT)
(TEST #6)
VERTICAL CATAPULT (DOTTED)
G'S
30
20
10
-10
-20
-30
50
100
150
200
250
300
350
TIME (MS)


HORIZONTAL TORSO WITH STANDARD CONFIGURATION (HEAVY)
HORIZONTAL TORSO WITH BIB AND NECK BAG (LIGHT)
VERTICAL CATAPULT (DOTTED)
(TEST #7)
G'S
30
20
10
-10
-20
-30
50
100
150
200
250
300
350
TIME (MS)


HORIZONTAL TORSO WITH STANDARD CONFIGURATION (HEAVY)
HORIZONTAL TORSO WITH BIB AND NECK BAG (LIGHT) (TEST #8)
VERTICAL CATAPULT (DOTTED)
G'S
30
20
10
-10
-20
-30
50
100
150
200
250
300
350
TIME (MS)

APPENDIX D

STUDENT T TEST OF TWO MEANS WITH PAIRED DATA

The horizontal head and horizontal chest data of table I was subjected to a paired data test.

SAMPLE CALCULATION FOR CHEST G_x

PEAK 'G'

Run No.	Ux (BIB)	U_y (CONTROL)
	x	y
1	10.21	16.23
2	10.28	16.94
3	11.80	24.27
	$\overline{x}$ = 10.76	$\overline{y}$ = 19.14

The hypothesis under test (null hypothesis) is:

H_o : $U_x = U_y$ where

U_x = mean value of x_1

U_y = mean value of y_1 and there is no significant difference between means,

The alternate hypothesis , H_a , is, H_a : $U_x < U_y$ which implies that U_x is significantly smaller than U_y .

The test statistic is
$$\frac{(\overline{x}-\overline{y})}{S_p\sqrt{\frac{1}{N_x}-\frac{1}{N_y}}}$$
and

$$S_p{}^2 = \frac{\Sigma(x-\overline{x})^2 + \Sigma(y-\overline{y})^2}{(n_x-1)+(n_y-1)}$$

$$\sum_{\ell=1}^{3}(x_n-\overline{x})^2 = (10.21-10.76)^2 + (10.28-10.76)^2 + (11.80-10.76)^2 =$$
$$0.31 + 0.23 + 1.08 = 1.62$$

$$\sum_{i=1}^{3}(y_n-\bar{y})^2 = (16.23-19.14)^2 + (16.94-19.14)^2 + (24.27-19.14)^2 = 8.47 + 4.84 + 26.31 = 39.63$$

$$S_p^2 = \frac{1.62 + 39.63}{2+2} = 10.3$$

$$S_p = \sqrt{10.3} = 3.21$$

With $S_p = 3.21$ and assuming a 95% confidence level $\alpha = 0.05$

Using $(n_x - 1) + (n_y - 1) = 4$ and,

from the Student T distribution tables ($\alpha = 0.05$ for a one-sided test)

the tabulated value is , -2.132

therefore,

$$\frac{(\bar{x} - \bar{y})}{(S_p)\sqrt{\frac{1}{n_x} + \frac{1}{n_y}}} = \frac{10.76 - 19.14}{(3.21)\sqrt{(1/3 + 1/3)}} = -3.2$$

Since $-3.2 < -2.132$ the hypothesis that $U_x = U_y$ is rejected and the hypothesis that $U_x < U_y$ is accepted.

Since a reduction in horizontal chest acceleration is desirable, then the BIB system is significantly better in terms of acceleration response. However, its merit in terms of improved safety is yet to be determined.

SAMPLE CALCULATION FOR HEAD G_x

PEAK ACCELERATION LEVEL

Run No.	U_x (BIB)	U_y (CONTROL)
	x	y
1	49.8	72.11
2	54.72	93.80
3	61.3	98.63
	$x = 55.27$	$y = 88.17$

The hypothesis under test (null hypothesis) is:

$H_o : U_x = U_y$ where

U_x = means value of x_1

U_y = mean value of y_1 and there is not significant difference between means,

The alternate hypothesis, H_a, is, $H_a : U_x < U_y$ which implies that U_x is significantly smaller than U_y.

The test statistic is $\dfrac{(\bar{x}-\bar{y})}{S_p\sqrt{\dfrac{1}{N_x} - \dfrac{1}{N_y}}}$ and

$$S_p^2 = \frac{\Sigma(x-\bar{x})^2 + \Sigma(y-\bar{y})^2}{(n_x-1)+(n_y-1)}$$

$$\sum_{n=1}^{3}(x_n-\bar{x})^2 = (49.8-55.3)^2 + (54.7-55.3)^2 + (61.3-55.3)^2 = 30.3 + 0.36 + 36 = 66.7$$

$$\sum_{n=1}^{3}(y_n-\bar{y})^2 = (72.1-88.17)^2 + (93.8-88.17)^2 + (98.6-88.17)^2 = 259.2 + 31.36 \quad 108.2 = 398.8$$

$$(S_p)^2 = \frac{(66.7) + (398.8)}{2 + 2} = 116.4 \quad \text{and} \quad S_p = \sqrt{116.4} = 10.8$$

With $S_p = 3.21$ and assuming a 95% confidence level $\alpha = 0.05$

Using $(n_x - 1) + (n_y - 1) = 4$ and,

From the Student T distribution tables ($\alpha = 0.05$ for a one-sided test) the tabulated value is , -2.132

therefore,
$$\frac{(\bar{x} - \bar{y})}{(S_p)\sqrt{\frac{1}{n_x} + \frac{1}{n_y}}} = \frac{55.27 - 88.17}{(10.8) \quad (1/3 + 1/3)} = -4.62$$

Since $-4.62 < -2.132$, the hypothesis that $U_x = U_y$ is rejected and the alternate hypothes that $U_x < U_y$ is accepted.

As before, since a reduction in the horizontal head acceleration is desirable, then the BIB system is significantly better than the standard configuration in terms of acceleration response of the head, but yet to be determined is its correlation to increased safety.

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